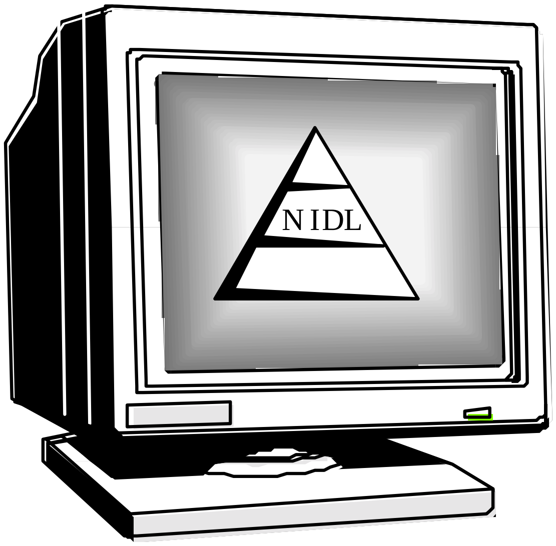

The Hitachi CM814U 21 inch monitor (20" viewable area, selling price $1200) has very good image quality and features that make it an excellent candidate color display for NIMA Imagery Exploitation Capability workstations. Based on our evaluation, NIDL certifies the Hitachi CM814U color monitor as being suitable for IEC workstations. NIDL rates this color monitor as a “B” for the Image Analyst and Cartographer applications. The “B” ratings, rather than “A”, result from slightly high halation and non-linearity values, and from a lower stereo extinction ratio and contrast modulation compared to the “A” rated, $2500, 24 inch Sun/Sony. In a light ambient, both monitors are calculated to achieve 158:1 dynamic range with 3 fc illumination, and 62:1 with 10 fc illumination falling onto the screen.

Evaluation of the Hitachi CM814U 4 x 3 Aspect Ratio, 21-Inch Diagonal Color CRT Monitor

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NIDL IEC Monitor Certification Report

The Hitachi CM814U Color CRT Monitor

FINAL GRADES
Monoscopic Mode: B
Stereoscopic Mode: B

A=Substantially exceeds IEC Requirements; B= Meets IEC Requirements; C=Nearly meets IEC Requirements; F=Fails to meet IEC Requirements in a substantial way

The Hitachi CM814U 21 inch color monitor (20" viewable area, selling price $1200) has very good image quality and features that make it an excellent candidate display device for NIMA Imagery Exploitation Capability workstations. Based on our evaluation, NIDL certifies the Hitachi CM814U color monitor as being suitable for IEC workstations. NIDL rates this color monitor as a “B” for the Image Analyst and Cartographer applications. The “B” ratings, rather than “A”, result from a slightly high halation and non-linearity values, and from a somewhat low stereo extinction ratio. In a light ambient, the monitor is calculated to achieve 158:1 dynamic range with 3 fc illumination, and 62:1 with 10 fc illumination falling onto the screen.

Easy to set up and run, the Hitachi CM814U is a versatile color monitor. It is a product of the well-regarded 3S Series of Super Space Saving monitors, and features a depth of only 406 mm (16 inches) and a flat, square CRT, 0.22mm horizontal dot pitch (0.16 mm vertical dot pitch), and high contrast, anti-static, anti-glare coat. The reliability of the Hitachi CM814U monitor is not known. The vertical line width at half maximum (FWHM) is 16.3 mils at 39 fL luminance and is 13.2 mils at 20 fL. The comparable horizontal line width is 14.7 mils a 39 fL and 11.5 mils at 20 fL. This corresponds to a resolution –addressability-ratio of 1.27. Values around 1-1.3 produce an image that is sharp and for which the scan lines are not evident.

The monitor nearly meets all IEC requirements in the monoscopic mode. The halation of 3.7% and the scan nonlinearity of 1.8% exceed the maximums allowed by the IEC specification so image sharpness and linearity across the face of the screen may be somewhat poorer than experienced with some other color displays. This monitor has no front panel control for adjustment of the linearity by the user. Also, the Hitachi CM814U fails the IEC specification in the stereo mode. The 11.2:1 extinction ratio determined with a NuVision stereo panel and passive glasses is less than required in the IEC specification. So, stereo performance may be less than experienced with a monochrome display, where extinction ratios >20:1 can be attained.

The manufacturer lists the maximum addressability as 1856 x 1392 pixels. However, the phosphor pitch of 0.22 mm horizontal limits the number of red, green and blue triads that can be addressed to less than 1856 pixels in the horizontal direction. In our evaluations, measurements for viewable image size of 15.436 x 11.575 inches indicate a maximum of 1782 pixels in the horizontal direction based on the pixel pitch.

The Hitachi CM814U monitor is described on the website, http://www.hitachidisplays.com

Color monitors are more difficult to evaluate and their performance may not compare to monochrome monitors. But, they do give the analyst the additional dimension of color for their tasks. Color monitors have three electron guns (R, G, and B) to focus and converge. They also have a perforated steel shadow mask that separates the colors on the screen and this adds complexity. Color lines formed on the phosphor screen may not be as narrow as for a monochrome, single electron gun-formed spot. The color monitor's light output may not be as high. The IEC monitor specifications for color monitors reflect this difference, and are less stringent than for a monochrome monitor. NIDL evaluated three monochrome monitors recently and found that they easily passed all the monoscopic and stereoscopic specifications; we recommended all three. Color monitors have a harder time passing all the less stringent IEC color monitor specifications and yet there are very good COTS color monitors on the market. Imagery analysts at a number of organizations do their analyses on color monitors. Thus, we are somewhat flexible in our grading for color monitors, since perfection is more difficult to achieve.

NIDL evaluated the Sun/Sony 24 inch color monitor, gave it an "A" for its performance, and recommended its use for imagery analysts. We based this recommendation on its measured performance, analysts' preference for the 24 inch diagonal, 16:10 format with its greater area, and reliability. The Hitachi CM814U monitor is a very good color monitor, but the 24 inch Sony performs better in the following areas:

- Uniformity
- Halation
- Contrast modulation, Zone A (nearly twice as high as the Hitachi)
- Contrast modulation, Zone B (nearly twice as high as the Hitachi)
- Linearity
- Warm-up time
- Extinction ratio in stereo

In ambient lighting with 3 or 10 fc falling onto the face of the monitor, both perform about the same.

The dimensions for the Hitachi are: 19.2 inch Wide x 19 inch High x 18.5 inch Deep x 61 pounds. The 24 inch Sony is 22.8 inch Wide x 19.8 inch High x 21.6 inch Deep x 90 pounds.

Thus price, $2500 for the 24 inch Sun/Sony versus about $1200 for the 21 inch Hitachi CM814U, and space available on the analyst's desk may be deciding factors in choice of color monitor in addition to performance.

Evaluation Datasheet

Mode	IEC Requirement	Measured Performance	Compliance
MONOSCOPIC			
Addressability	1024 x 1024 min.	1600 x 1200	pass
Dynamic Range	24.7dB	25.46 dB	pass
Luminance (Lmin)	0.1 fL min ± 4%	0.11 fL	pass
Luminance (Lmax)	30 fL ± 4%	38.7 fL	pass
Uniformity (Lmax)	20% max.	19.1 %	pass
Halation	3.5% max.	4.0± 0.3%	fail
Color Temp	6500 to 9300 K	8306 K	pass
Reflectance	Not specified	5.3 %	
Bit Depth	8-bit± 5 counts	8-bit	pass
Step Response	No visible ringing	Clean	pass
Uniformity (Chromaticity)	0.010 Δ u'v'max.	0.005 Δ u'v'	pass
Pixel aspect ratio	Square, H = V± 6%	Set to square	pass
Screen size, viewable diagonal	17.5 to 24 inches ± 2 mm	19.294 inches	pass
Cm, Zone A, 40% circle, 9.54 inch	25% min.	35 %	pass
Cm, Zone B	20% min.	30 %	pass
Pixel density	72 ppi min.	104 ppi	pass
Moiré, phosphor-to-pixel spacing	1.0 max	0.9	pass
Straightness	0.5% max ± 0.02%	0.2%	pass
Linearity	1.0% max ± 0.6%	1.78 %	fail
Jitter	2 ± 2 mils max.	2.44 mils	pass
Swim, Drift	5 ± 2 mils max.	2.68 mils	pass
Warm-up time, Lmin to +/- 50%	30 mins. Max ± 0.5 minute	26 min.	pass
Warm-up time, Lmin to +/- 10%	60 mins. Max ± 0.5 minute	60 mins.	pass
Refresh	72 ±1 Hz min. 60 ±1 Hz absolute minimum	Set to 72 Hz	pass
STEREOSCOPIC			
Addressability	1024 x 1024 min.	1024 x 1024	pass
Lmin	Not specified	0.10 fL	
Lmax	6 fL min ± 4%	7.76 fL	pass
Dynamic range	17.7 dB min	18.9 dB	pass
Uniformity (Chromaticity)	0.02 Δ u'v'max	0.006 Δ u'v'	pass
Refresh rate	60 Hz per eye, min	60 Hz	pass
Extinction Ratio	15:1 min	11.2: 1	fail
AMBIENT LIGHTING			
Dynamic Range 22 dB (158:1)	No specification	3 fc	
Dynamic Range 17.9 dB (62:1)	No specification	10 fc	

(I) denotes interlaced scanning
(n) denotes Nuvision LCD shutter panel

Section I INTRODUCTION

The National Information Display Laboratory (NIDL) was established in 1990 to bring together technology providers - commercial and academic leaders in advanced display hardware, softcopy information processing tools, and information collaboration and communications techniques - with government users. The Sarnoff Corporation in Princeton, New Jersey, a world research leader in high-definition digital TV, advanced displays, computing and electronics, hosts the NIDL.

The present study evaluates a production unit of the Hitachi CM814U, color CRT high-resolution display monitor. This report is intended for both technical users, such as system integrators, monitor designers, and monitor evaluators, and non-technical users, such as image analysts, software developers, or other users unfamiliar with detailed monitor technology.

The IEC requirements, procedures and calibrations used in the measurements are detailed in the following:

- *NIDL Publication No. 0201099-091*, *Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC),* August 25, 1999.

Two companion documents that describe how the measurements are made are available from the NIDL and the Defense Technology Information Center at http://www.dtic.mil:

- *NIDL Publication No. 171795-036 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 1: Monochrome CRT Monitor Performance Draft Version 2.0. (ADA353605)*

- *NIDL Publication No. 171795-037 Display Monitor Measurement Methods under Discussion by EIA (Electronic Industries Association) Committee JT-20 Part 2: Color CRT Monitor Performance Draft Version 2.0. (ADA341357)*

Other procedures are found in a recently approved standard available from the Video Electronics Standards Association (VESA) at http://www.vesa.org:

- *VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998.*
  Publication No. 0201099-091, Request for Evaluation Monitors for the National Imagery & Mapping Agency (NIMA) Integrated Exploitation Capability (IEC), August 25, 1999.

The IEC workstation provides the capability to display image and other geospatial data on either monochrome or color monitors, or a combination of both. Either of these monitors may be required to support stereoscopic viewing. Selection and configuration of these monitors will be made in accordance with mission needs for each site. NIMA users will select from monitors included on the NIMA-approved Certified Monitor List compiled by the NIDL. The color and monochrome, monoscopic and stereoscopic, monitor requirements are listed in the Evaluation Datasheet.

I.1 The Hitachi CM814U Color CRT Monitor

Hitachi’s Specifications

According to Hitachi, the specifications for the Hitachi CM814U monitor are:

Part of the 3S Series of Super Space Saving monitors, Hitachi's 814U features a depth of only 406 mm.

Specifications	**SuperScan CM814U**
Auto synchronization range	31-125 kHz, 50-160 Hz
Maximum resolution	2048 x 1536
Maximum refresh rates	
640 x 480	160 Hz
800 x 600	160 Hz
1024 x 768	150 Hz
1280 x 1024	115 Hz
1600 x 1200	100 Hz
1856 x 1392*	85 Hz
2048 x 1536*	75 Hz
Video clock frequency	270 MHz
Microprocessor presets	
Standard presets	7
User programmable	19
Signal cable (included)	15 pin D-sub
Input Signal, Video	0.70 Vp-p, Analog
Sync.	Separate H/V, TTL level, Composite H/V
	Sync on Green, 0.3 Vp-p
Resolution, max	1856 dots x 1392 lines
Viewable image size	20.0 inches diagonal, 406 mm horiz, x 305 mm vert.
Color Temp (4 presets)	9300 K, 6500 K, 5000 K, User-defined
Warm-up Time	30 minutes
Temperature	5 deg to 35 deg C operation
Humidity	10% to 80% operation

CRT 21" (20" viewable image size) flat, square** CRT with Hitachi's exclusive PrecisionFocus™ technology. 0.22mm horizontal dot pitch, 0.16 mm vertical dot pitch. Multi-step dynamic focus. Auto-astigmatism correction. Black matrix with Invar Shadow Mask. High contrast, anti-static, anti-glare coat. 406 mm x 305 mm viewable image area. 814-521 & 813-521: Now with Super High Contrast tube, 10% sharper and 15% brighter than other CRT's and is USB optional (requires separate purchase of Hitachi's DUB-O1A USB hub) with 1 up / 4 downstream ports. ** *Flat, square is an industry standard term used since 1997 indicating minimal curvature of the monitor tube. This does not mean that the monitor is completely flat. Please call Hitachi customer relations if you have further questions.*

Digital controls Power, RGB color, white balance (9300K, 6500K, 5000K, and user defined), brightness, contrast, H/V position and size, rotation, pincushion (side and right), trapezoid, right

trapezoid, degauss, memory store, H/V moiré on/off, H/V moiré adjustment, language select and EasyMenu™ on-screen control.

Power supply120/240 V (auto adjusting), 50/60 Hz. 130W typical (4W at power off).

Size/weight 19.2" W x 19" H x 18.5" D (61 lbs.), including detachable tilt/swivel base.

Regulatory compliance

Safety: UL1950, CSA C22.2 No 950, EN60950, SEMKO, DEMKO, NEMKO, SETI, CB.
Ergonomics: ZH 1/618,1SO 9241 -3.
X-radiation: DHHS, RoV.
EMI: FCC Class B (813, 811), FCC ClassA (814), EN55022 Class-B
MPR Il: TUV Ergo certified.
TCO: TCO'95
Energy saving: EPA Energy Star, VESA DPMS.

Hitachi's 3S series of Super Space Saving monitors includes the SuperScan 814. It features a short-neck CRT design and the shortest depth available on any 21-inch monitor. This 20-inch viewable image monitor has a variety of features to meet the needs of imaging, graphics or multimedia professionals. It has the space, resolutions, refresh rates and image quality required by today's complex applications. An exceptionally fine .22mm horizontal dot pitch and Hitachi's flat square tube with multi-step dynamic focus and auto-astigmatism correction combine to produce Hitachi's sharpest image, with precise focus and consistent brightness out to the corners and edges. The SuperScan 814, with black matrix Invar shadow mask, supports a max resolution of 1856x1392 at 85Hz flicker-free, with refresh rates up to 160Hz. It runs at 1600x1200 resolution at 100Hz refresh, with a 270MHz video clock frequency. It's a clear choice for eye-saving viewing. The built-in precise color control, optimum white balance and consistent screen geometry bolsters color graphics creation. Easy Menu on-screen controls give access to seven preset and 19 user programmable picture adjustments in five languages. The SuperScan 814 is plug and play ready for easy setup and use under Windows 95. It complies with strict TCO '95 standards for safe emissions levels, and its power management features meet EPA Energy Star / VESA DPMS requirements. This model also has a universal power supply for configuration flexibility.

I.2. Initial Monitor Set Up

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5, p 5.

All measurements will be made with the display commanded through a laboratory grade programmable test pattern generator. The system will be operated in at least a 24 bit mode (as opposed to a lesser or pseudo-color mode) for color and at least 8 bits for monochrome. As a first step, refresh rate should be measured and verified to be at least 72 Hz. The screen should then be commanded to full addressability and Lmin set to 0.1 fL. Lmax should be measured at screen center with color temperature between D65 and D93 allowable and any operator adjustment of gain allowable. If a value >35fL is not achieved (>30 fL for color), addressability should be lowered. For a nominal 1200 by 1600 addressability, addressability should be lowered to 1280 by 1024 or to 1024 by 1024. For a nominal 2048 by 2560 addressability, addressabilities of 1200 x 1600 and 1024 x 1024 can be evaluated if the desired Lmax is not achieved at full addressability.

I.3. Equipment

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 2.0, page 3.

The procedures described in this report should be carried out in a darkened environment such that the stray luminance diffusely reflected by the screen in the absence of electron-beam excitation is less than 0.003 cd/m^2 (1mfL).

Instruments used in these measurements included:

- Quantum Data 8701 400 MHz programmable test pattern signal generator
- Quantum Data 903 250 MHz programmable test pattern signal generator
- Photo Research SpectraScan PR-650 spectroradiometer
- Photo Research SpectraScan PR-704 spectroradiometer
- Minolta LS-100 Photometer
- Minolta CA-100 Colorimeter
- Graseby S370 Illuminance Meter
- Microvision Superspot 100 Display Characterization System which included OM-1 optic module (Two Dimensional photodiode linear array device, projected element size at screen set to 1.3 mils with photopic filter) and Spotseeker 4-Axis Positioner

Stereoscopic-mode measurements were made using the following commercially-available stereo products:

- Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Section II PHOTOMETRIC MEASUREMENTS

II.1. Dynamic range and Screen Reflectance

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.*

VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 199, Section 308-1.

Full screen white-to-black dynamic range measured in 1600 x 1200 format is 25.5 dB in a dark room. It is less than 22 dB (the absolute threshold for IEC) in 3 fc diffuse ambient illumination.

Objective: Measure the photometric output (luminance vs. input command level) at Lmax and Lmin in both dark room and illuminated ambient conditions.

Equipment: Photometer, Integrating Hemisphere Light Source or equivalent

Procedure: Luminance at center of screen is measured for input counts of 0 and Max Count. Test targets are full screen (flat fields) where full screen is defined addressability. Set Lmin to 0.1 fL. For color monitors, set color temperature between D_{65} to D_{93}. Measure Lmax.

This procedure applies when intended ambient light level measured at the display is 2fc or less. For conditions of higher ambient light level, Lmin and Lmax should be measured at some nominal intended ambient light level (e.g., 18-20 fc for normal office lighting with no shielding). This requires use of a remote spot photometer following procedures outlined in reference 2, paragraph 308-2. This will at best be only an approximation since specular reflections will not be captured. A Lmin > 0.1 fL may be required to meet grayscale visibility requirements.

According to the VESA directed hemispherical reflectance (DHR) measurement method, total combined reflections due to specular, haze and diffuse components of reflection arising from uniform diffuse illumination are simultaneously quantified as a fraction of the reflectance of a perfect white diffuse reflector using the set up depicted in figure II.1-1. Total reflectance was calculated from measured luminances reflected by the screen (display turned off) when uniformly illuminated by an integrating hemisphere simulated using a polystyrene icebox. Luminance is measured using a spot photometer with 1° measurement field and an illuminance sensor as depicted in Figure II.1-1. The measured values and calculated reflectances are given in Table II.1-1.

Data: Define dynamic range by: DR=10log(Lmax/Lmin)

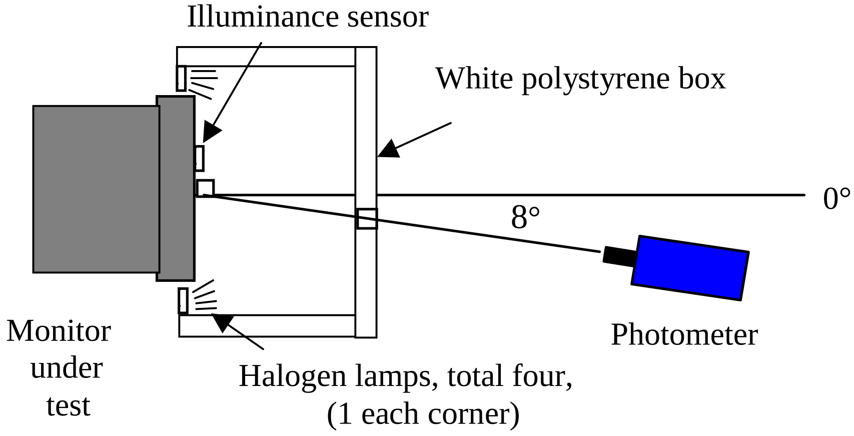


Figure II.1-1. Test setup according to VESA FPDM procedures for measuring total reflectance of screen.

Table II.1-1. Directed Hemispherical Reflectance of Faceplate

VESA ambient contrast illuminance source (polystyrene box)

Ambient Illuminance	20.2 fc
Reflected Luminance	1.07 fL
Faceplate Reflectance	5.3 %

Ambient dynamic ranges of full screen white-to-black given in Table II.1-2 were computed for various levels of diffuse ambient lighting using the measured value for DHR and the darkroom dynamic range measurements. Full screen white-to-black dynamic range decreases from 25.5 dB in a dark room to 22 dB (the absolute threshold for IEC) in 3 fc diffuse ambient illumination.

Table II.1-2.Dynamic Range in Dark and Illuminated Rooms

Effect of ambient lighting on dynamic range is calculated by multiplying the measured CRT faceplate reflectivity times the ambient illumination measured at the CRT in foot candles added to the minimum screen luminance, Lmin, where Lmin = 0.1 fL.

Ambient Illumination	**Dynamic Range**
0 fc (Dark Room)	25.5 dB
1 fc	23.8 dB
2 fc	22.5 dB
3 fc	21.6 dB
4 fc	20.8 dB
5 fc	20.2 dB
6 fc	19.6 dB
7 fc	19.1 dB
8 fc	18.6 dB
9 fc	18.2 dB
10 fc	17.9 dB

II.2. Maximum Luminance (Lmax)

References: *Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.2, p 6.*

The highest luminance for Lmax was 38.7fL measured at screen center in 1600 x 1200 format.

Objective: Measure the maximum output display luminance.

Equipment: Photometer

Procedure: See dynamic range. Use the value of Lmax defined for the Dynamic Range measurement.

Data: The maximum output display luminance, Lmax, and associated CIE x, y chromaticity coordinates (CIE 1976) were measured using a hand-held colorimeter (Minolta CA-100). The correlated color temperature (CCT) computed from the measured CIE x, y chromaticity coordinates was within range specified by IEC (6500K and 9300K).

Table II.2-1. Maximum Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at screen center.

Format	CCT	CIE x	CIE y	Luminance
1600 x 1200	8306 K	0.289	0.311	38.7 fL

II.3. Luminance (Lmax) and Color Uniformity

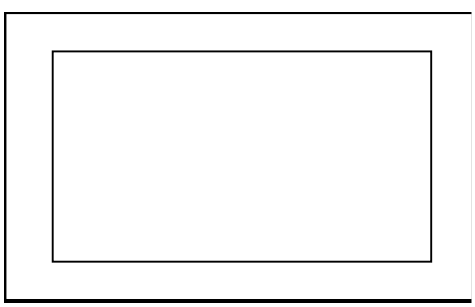
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 4.4, p. 28.

Maximum luminance (Lmax) varied by up to 19.1 % across the screen. Chromaticity variations were less than 0.005 delta u'v' units.

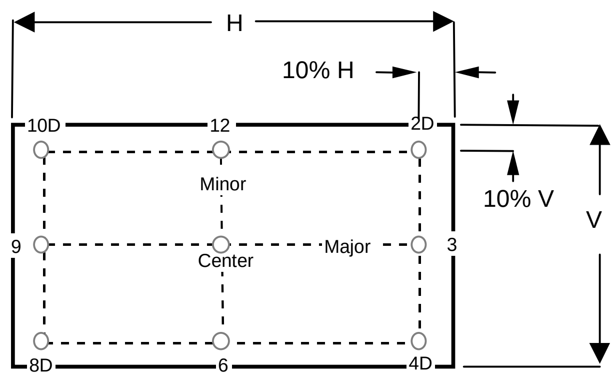
Objective: Measure the variability of luminance and chromaticity coordinates of the white point at 100% Lmax only and as a function of spatial position. Variability of luminance impacts the total number of discriminable gray steps.

Equipment:
- Video generator
- Photometer
- Spectroradiometer or Colorimeter

Test Pattern: Full screen flat field with visible edges at L_{min} as shown in Figure II.3-1.



Full Screen Flat Field test pattern.
Figure II.3-1



Nine screen test locations.
Figure II.3-2

Procedure: Investigate the temporal variation of luminance and the white point as a function of intensity by displaying a full flat field shown in Figure II.3-1 for video input count levels corresponding L_{max}. Measure the luminance and C.I.E. color coordinates at center screen.

Investigate the temporal variation of luminance and the white point as a function of spatial position by repeating these measurements at each of the locations depicted in Figure II.3-2. Define color uniformity in terms of Δ u´v´.

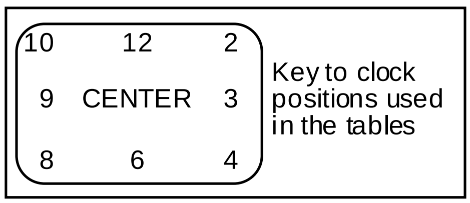
Data: Tabulate the luminance and 1931 C.I.E. chromaticity coordinates (x, y) or correlated color temperature of the white point at each of the nine locations depicted in Figure II.3-2. Additionally, note the location of any additional points that are measured along with the corresponding luminance values.

Table II.3-1.Spatial Uniformity of Luminance and Color

Color and luminance (in fL) for Full screen at 100% Lmax taken at nine screen positions.

1600 x 1200

POSITION	CCT	CIE x	CIE y	L, fL
center	8306	0.289	0.311	38.7
2	8458	0.287	0.311	33.6
3	8205	0.289	0.315	32.5
4	8660	0.284	0.312	33.2
6	8751	0.284	0.309	36.5
8	8751	0.284	0.309	33.1
9	8912	0.282	0.309	31.3
10	8592	0.286	0.309	32.1
12	8486	0.287	0.310	35.1



1600 x 1200

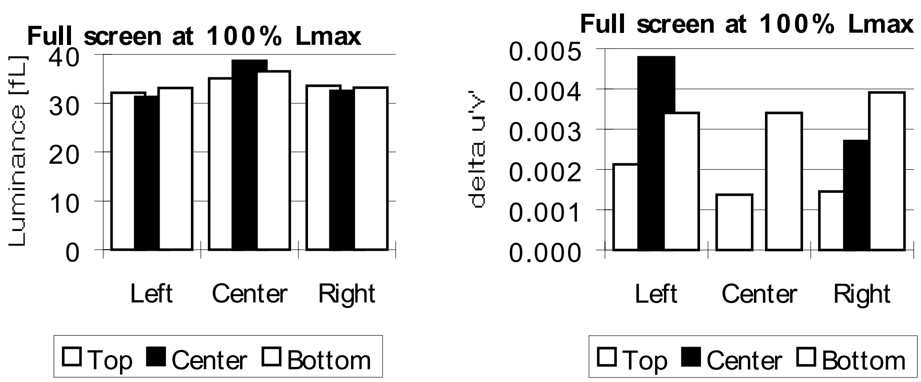


Fig.II.3-3. Spatial Uniformity of Luminance and Chromaticity. (Delta u'v' of 0.004 is just visible.)

II.4. Halation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 4.6, page 48.

Halation was 4.0% ±0.3% on a small black patch surrounded by a large full white area.

Objective: Measure the contribution of halation to contrast degradation. Halation is a phenomenon in which the luminance of a given region of the screen is increased by contributions from surrounding areas caused by light scattering within the phosphor layer and internal reflections inside the glass faceplate. The mechanisms that give rise to halation, and its detailed non-monotonic dependence on the distance along the screen between the source of illumination and the region being measured have been described by E. B. Gindele and S.L. Shaffer. The measurements specified below determine the percentage of light that is piped into the dark areas as a function of the extent of the surrounding light areas.

Equipment:

- Photometer
- Video generator

Test Pattern:

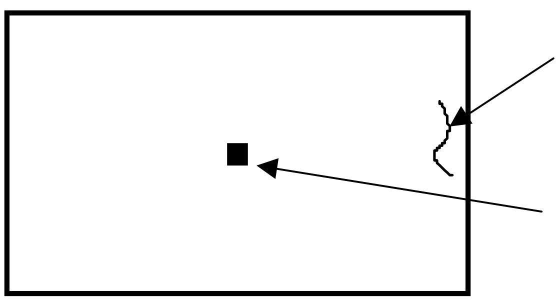


Figure II.4-1 *Test pattern for measuring halation.*

Procedure: Note: The halation measurements require changing the setting of the BRIGHTNESS control and will perturb the values of L_{max} and L_{min} that are established during the initial monitor set-up. The halation measurements should therefore be made either first, before the monitor setup, or last, after all other photometric measurements have been completed.

Determine halation by measuring the luminance of a small square displayed at L_{black} (essentially zero) and at L_{white} when surrounded by a much larger square displayed at L_{white} (approximately 75% L_{max}).

Establish L_{black} by setting the display to cutoff. To set the display to cut-off, display a flat field using video input count level zero, and use a photometer to monitor the luminance at center screen. Vary the BRIGHTNESS control until the CRT beam is visually cut off, and confirm that the corresponding luminance (L_{stray}) is essentially equal to zero. Fine tune the BRIGHTNESS control such that

CRT beam is just on the verge of being cut off. These measurements should be made with a photometer, which is sensitive at low light levels (below L_{min} of the display). Make no further adjustments or changes to the BRIGHTNESS control or the photometer measurement field.

Next, decrease the video input level to display a measured full-screen luminance of 75% L_{max} measured at screen center. Record this luminance (L_{white}).

The test target used in the halation measurements is a black (L_{black}) square patch of width equal to 0.01% of the area of addressable screen, the interior square as shown in Figure II.4-1. The interior square patch is enclosed in a white (L_{white}) background encompassing the remaining area of the image. The exterior surround will be displayed at 75% L_{max} using the input count level for L_{white} as determined above. The interior square will be displayed at input digital count level zero.

Care must be taken during the luminance measurement to ensure that the photometer's measurement field is less than one-half the size of the interior square and is accurately positioned not to extend beyond the boundary of the interior square. The photometer should be checked for light scattering or lens flare effects which allow light from the surround to enter the photosensor. A black card with aperture equal to the measurement field (one-half the size of the interior black square) may be used to shield the photometer from the white exterior square while making measurements in the interior black square.

Analysis: Compute the percent halation for each test target configuration. Percent halation is defined as:

$$\% \text{ Halation} = L_{black} / (L_{white} - L_{black}) \times 100$$

Where, L_{black} = measured luminance of interior square displayed at L_{black} using input count level zero,

L_{white} = measured luminance of interior square displayed at L_{white} using input count level determined to produce a full screen luminance of 75% L_{max} .

Data: Table II.4-1 contains measured values of L_{black}, L_{white} and percentage halation.

Table II.4-1 Halation for 1600 x 1200 Addressability

	Reported Values	Range for 4% uncertainty
Lblack	1.0 fL ± 4%	0.98 fL to 1.06 fL
Lwhite	25.6 fL ± 4%	24.6 fL to 26.6 fL
Halation	**4.0% ± 0.3%**	**3.66% to 4.30%**

II.5. Color Temperature

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 5.4, page 22.

The CCT of 8306K for the measured white point lies within 0.004 Δ u'v' from the day light locus accepted by IEC (0.010 Δ u'v' maximum is allowed).

Objective: Insure measured screen white of a color monitor has a correlated color temperature (CCT) between 6500K and 9300K.

Equipment: Colorimeter

Procedure: Command screen to Lmax. Measure u'v' chromaticity coordinates (CIE 1976).

Data: Coordinates of screen white should be within 0.01 Δu'v' of the corresponding CIE daylight, which is defined as follows: If the measured screen white has a CCT between 6500 and 9300 K, the corresponding daylight has the same CCT as the screen white. If the measured CCT is greater than 9300 K, the corresponding daylight is D93. If the measured CCT is less than 6500 K, the corresponding daylight is D65. The following equations were used to compute Δu'v' values listed in table II.5.1:

1. Compute the correlated color temperature (CCT) associated with (x, y) by the VESA/McCamy formula: CCT = 437 n^3 + 3601 n^2 + 6831 n + 5517, where n = (x-0.3320)/(0.1858 - y). [This is on p. 227 of the FPDM standard]

2. If CCT < 6500, replace CCT by 6500. If CCT > 9300, replace CCT by 9300.

4. Use formulas 5(3.3.4) and 6(3.3.4) in Wyszecki and Stiles (pp.145-146 second edition) to compute the point (xd,yd) associated with CCT.
   - First, define u = 1000/CCT.
   - If CCT < 7000, then xd = -4.6070 u^3 + 2.9678 u^2 + 0.09911 u +
   - 0.244063.
   - If CCT > 7000, then xd = -2.0064 u^3 + 1.9018 u^2 + 0.24748 u +
   - 0.237040.
   - In either case, yd = -3.000 xd^2 + 2.870 xd -0.275.

5. Convert (x,y) and (xd,yd) to u'v' coordinates:
   - (u',v') = (4x,9y)/(3 + 12y - 2x)
   - (u'd,v'd) = (4xd,9yd)/(3 + 12yd - 2xd)

6. Evaluate delta-u'v' between (u,v) and (ud,vd):
   - delta-u'v' = sqrt[(u' - u'd)^2 + (v' - v'd)^2].

7. If delta-u'v' is greater than 0.01, display fails the test. Otherwise it passes the test.

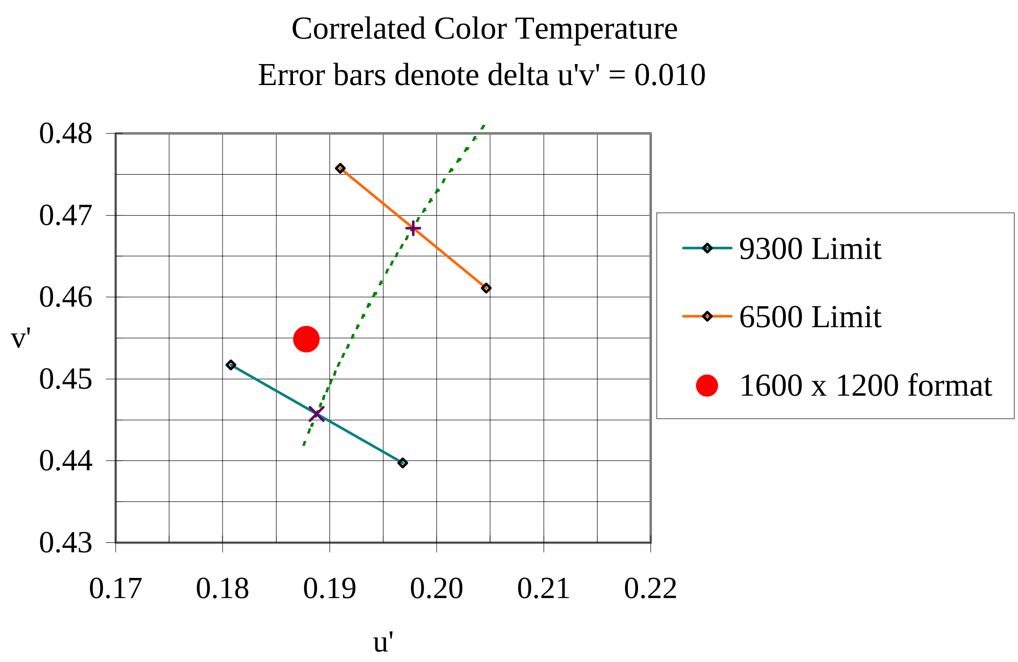


Figure II.5-1 *CCTs of measured whitepoints are within the boundaries required by IEC.*

Table II.5-1 Δu'v' Distances between measured whitepoints and CIE coordinate values from D_{65} to D_{93}.

	1600 x 1200
CIE x	0.289
CIE y	0.311
CIE u'	0.188
CIE v'	0.455
CCT	8306
delta u'v'	0.004

II.6. Bit Depth

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.6, p 6.

Monotonic increases in luminance were measured for each of the 256 input levels for 8 bits of gray scale. Neither black level clipping nor white level saturation was observed.

Objective: Measure the number of bits of data that can be displayed as a function of the DAC and display software.

Equipment: Photometer

Test targets: Targets are four inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels.

Procedure: Measure patch center for all patches with Lmin and Lmax as defined previously. Count number of monotonically increasing luminance levels. Use the NEMA/DICOM F500to define discriminable luminance differences. For color displays, measure white values.

Data: Define bit depth by $\log_2$ (number of discrete luminance levels)

The number of bits of data that can be displayed as a function of the input signal voltage level were verified through measurements of the luminance of white test targets displayed using a Quantum Data 8701 test pattern generator and a Minolta CA-100 colorimeter. Targets are n four-inch patches with command levels of all commandable levels; e.g., 256 for 8 bit display. Background is commanded to 0.5* ((0.7 *P)+0.3*n) where P = patch command level, n = number of command levels. The NEMA/DICOM F500was used to define discriminable luminance differences in JNDs.

Figure II.6-1 shows the System Tonal Transfer curve at center screen as a function of input counts. The data for each of the 256 levels are listed in Tables II.6-1 and II.6-2.

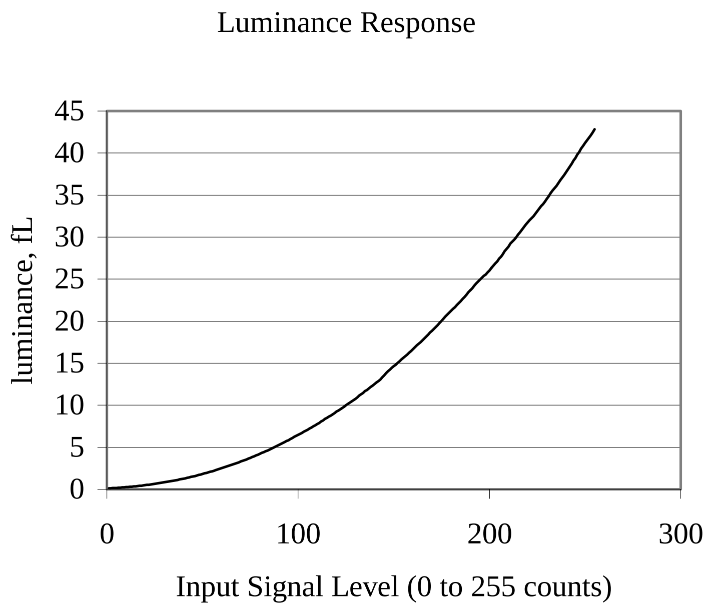


Figure II.6-1. System Tonal Transfer at center screen as a function of input counts.

Table II.6-1. System Tonal Transfer at center screen as a function of input counts.
Target levels 000 to 127.

Back Ground	Target	L, fL	Diff, fL	Diff, JND	Back Ground	Target	L, fL	Diff, fL	Diff, JND
38	0	0.108	0	0	61	64	2.807	0.084	3
39	1	0.12	0.012	3	61	65	2.887	0.08	2
39	2	0.132	0.012	3	62	66	2.971	0.084	3
39	3	0.144	0.012	3	62	67	3.047	0.076	2
40	4	0.156	0.012	2	62	68	3.126	0.079	2
40	5	0.169	0.013	3	63	69	3.216	0.09	3
41	6	0.185	0.016	3	63	70	3.298	0.082	2
41	7	0.201	0.016	3	63	71	3.386	0.088	3
41	8	0.216	0.015	2	64	72	3.467	0.081	2
42	9	0.232	0.016	3	64	73	3.552	0.085	2
42	10	0.251	0.019	3	64	74	3.645	0.093	3
42	11	0.27	0.019	3	65	75	3.739	0.094	2
43	12	0.292	0.022	3	65	76	3.835	0.096	2
43	13	0.313	0.021	3	65	77	3.926	0.091	3
43	14	0.333	0.02	3	66	78	4.025	0.099	2
44	15	0.356	0.023	2	66	79	4.112	0.087	2
44	16	0.385	0.029	4	66	80	4.223	0.111	2
44	17	0.41	0.025	3	67	81	4.328	0.105	3
45	18	0.436	0.026	3	67	82	4.422	0.094	2
45	19	0.462	0.026	3	67	83	4.524	0.102	2
45	20	0.488	0.026	2	68	84	4.617	0.093	2
46	21	0.518	0.03	3	68	85	4.725	0.108	3
46	22	0.547	0.029	3	69	86	4.836	0.111	2
46	23	0.577	0.03	3	69	87	4.956	0.12	2
47	24	0.61	0.033	3	69	88	5.055	0.099	2
47	25	0.643	0.033	3	70	89	5.163	0.108	2
48	26	0.674	0.031	2	70	90	5.277	0.114	3
48	27	0.71	0.036	3	70	91	5.388	0.111	2
48	28	0.745	0.035	3	71	92	5.502	0.114	2
49	29	0.781	0.036	3	71	93	5.618	0.116	2
49	30	0.82	0.039	3	71	94	5.738	0.12	2
49	31	0.859	0.039	3	72	95	5.843	0.105	2
50	32	0.901	0.042	2	72	96	5.986	0.143	3
50	33	0.942	0.041	3	72	97	6.103	0.117	2
50	34	0.986	0.044	3	73	98	6.229	0.126	2
51	35	1.031	0.045	3	73	99	6.357	0.128	2
51	36	1.07	0.039	2	73	100	6.471	0.114	2
51	37	1.118	0.048	3	74	101	6.587	0.116	2
52	38	1.164	0.046	3	74	102	6.719	0.132	2
52	39	1.211	0.047	3	74	103	6.838	0.119	2
52	40	1.259	0.048	2	75	104	6.976	0.138	2
53	41	1.312	0.053	3	75	105	7.092	0.116	2
53	42	1.363	0.051	3	76	106	7.238	0.146	2
53	43	1.415	0.052	3	76	107	7.346	0.108	1
54	44	1.469	0.054	2	76	108	7.489	0.143	3
54	45	1.524	0.055	3	77	109	7.618	0.129	1
55	46	1.578	0.054	3	77	110	7.764	0.146	3
55	47	1.638	0.06	2	77	111	7.898	0.134	1
55	48	1.709	0.071	3	78	112	8.061	0.163	3
56	49	1.768	0.059	3	78	113	8.196	0.135	2
56	50	1.826	0.058	3	78	114	8.371	0.175	2
56	51	1.89	0.064	2	79	115	8.487	0.116	1
57	52	1.954	0.064	3	79	116	8.628	0.141	2
57	53	2.021	0.067	3	79	117	8.771	0.143	2
57	54	2.087	0.066	2	80	118	8.922	0.151	2
58	55	2.151	0.064	3	80	119	9.077	0.155	2
58	56	2.217	0.066	2	80	120	9.243	0.166	2
58	57	2.286	0.069	3	81	121	9.366	0.123	2
59	58	2.363	0.077	2	81	122	9.531	0.165	2
59	59	2.431	0.068	3	81	123	9.687	0.156	1
59	60	2.502	0.071	2	82	124	9.824	0.137	2
60	61	2.571	0.069	2	82	125	10.03	0.206	2
60	62	2.652	0.081	3	83	126	10.16	0.13	2
60	63	2.723	0.071	2	83	127	10.32	0.16	2

Table II.6-2. System Tonal Transfer at center screen as a function of input counts Target levels 128 to 255.

Back ground	Target	L, fL	Diff, fL	Diff, JND
83	128	10.47	0.15	1
84	129	10.64	0.17	2
84	130	10.79	0.15	2
84	131	10.98	0.19	2
85	132	11.15	0.17	2
85	133	11.31	0.16	1
85	134	11.47	0.16	2
86	135	11.67	0.2	2
86	136	11.82	0.15	2
86	137	12	0.18	1
87	138	12.17	0.17	2
87	139	12.35	0.18	2
87	140	12.52	0.17	2
88	141	12.7	0.18	1
88	142	12.87	0.17	2
88	143	13.07	0.2	2
89	144	13.31	0.24	2
89	145	13.57	0.26	2
90	146	13.82	0.25	2
90	147	14.03	0.21	2
90	148	14.24	0.21	2
91	149	14.45	0.21	2
91	150	14.66	0.21	2
91	151	14.82	0.16	1
92	152	15.03	0.21	2
92	153	15.24	0.21	1
92	154	15.46	0.22	2
93	155	15.66	0.2	2
93	156	15.84	0.18	1
93	157	16.02	0.18	2
94	158	16.24	0.22	1
94	159	16.46	0.22	2
94	160	16.68	0.22	2
95	161	16.89	0.21	1
95	162	17.12	0.23	2
95	163	17.32	0.2	1
96	164	17.51	0.19	2
96	165	17.74	0.23	1
97	166	17.96	0.22	2
97	167	18.19	0.23	2
97	168	18.41	0.22	1
98	169	18.64	0.23	2
98	170	18.85	0.21	1
98	171	19.08	0.23	2
99	172	19.29	0.21	1
99	173	19.54	0.25	2
99	174	19.78	0.24	1
100	175	20.04	0.26	2
100	176	20.28	0.24	1
100	177	20.56	0.28	2
101	178	20.78	0.22	2
101	179	21.02	0.24	1
101	180	21.25	0.23	1
102	181	21.46	0.21	2
102	182	21.67	0.21	1
102	183	21.92	0.25	2
103	184	22.15	0.23	1
103	185	22.39	0.24	1
104	186	22.65	0.26	2
104	187	22.89	0.24	1
104	188	23.15	0.26	2
105	189	23.44	0.29	1
105	190	23.68	0.24	2
105	191	23.91	0.23	1

Back ground	Target	L, fL	Diff, fL	Diff, JND
106	192	24.22	0.31	2
106	193	24.47	0.25	1
106	194	24.7	0.23	1
107	195	24.94	0.24	1
107	196	25.18	0.24	2
107	197	25.39	0.21	1
108	198	25.55	0.16	1
108	199	25.82	0.27	1
108	200	26.05	0.23	1
109	201	26.36	0.31	2
109	202	26.63	0.27	1
109	203	26.87	0.24	1
110	204	27.12	0.25	1
110	205	27.46	0.34	2
111	206	27.68	0.22	1
111	207	27.96	0.28	2
111	208	28.32	0.36	1
112	209	28.58	0.26	1
112	210	28.84	0.26	2
112	211	29.22	0.38	1
113	212	29.48	0.26	2
113	213	29.71	0.23	1
113	214	29.97	0.26	1
114	215	30.3	0.33	1
114	216	30.56	0.26	1
114	217	30.88	0.32	2
115	218	31.17	0.29	1
115	219	31.49	0.32	1
115	220	31.76	0.27	2
116	221	32.02	0.26	1
116	222	32.24	0.22	1
116	223	32.49	0.25	1
117	224	32.78	0.29	1
117	225	33.1	0.32	1
118	226	33.38	0.28	1
118	227	33.68	0.3	2
118	228	33.92	0.24	1
119	229	34.24	0.32	1
119	230	34.58	0.34	1
119	231	34.88	0.3	1
120	232	35.27	0.39	2
120	233	35.55	0.28	1
120	234	35.83	0.28	1
121	235	36.11	0.28	1
121	236	36.43	0.32	1
121	237	36.77	0.34	2
122	238	37.07	0.3	1
122	239	37.39	0.32	1
122	240	37.73	0.34	1
123	241	38.06	0.33	1
123	242	38.41	0.35	2
123	243	38.76	0.35	1
124	244	39.08	0.32	1
124	245	39.42	0.34	1
125	246	39.81	0.39	2
125	247	40.13	0.32	1
125	248	40.54	0.41	1
126	249	40.86	0.32	1
126	250	41.18	0.32	1
126	251	41.51	0.33	1
127	252	41.8	0.29	1
127	253	42.12	0.32	1
127	254	42.44	0.32	1
128	255	42.82	0.38	2

II.8. Luminance Step Response

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.8, p 7.

No video artifacts were observed.

Objective: Determine the presence of artifacts caused by undershoot or overshoot.

Equipment: Test targets, SMPTE Test Pattern RP-133-1991, 2-D CCD array

Procedure: Display a center box 15% of screen size at input count levels corresponding to 25%, 50%, 75%, and 100% of Lmax with a surround of count level 0. Repeat using SMPTE Test pattern

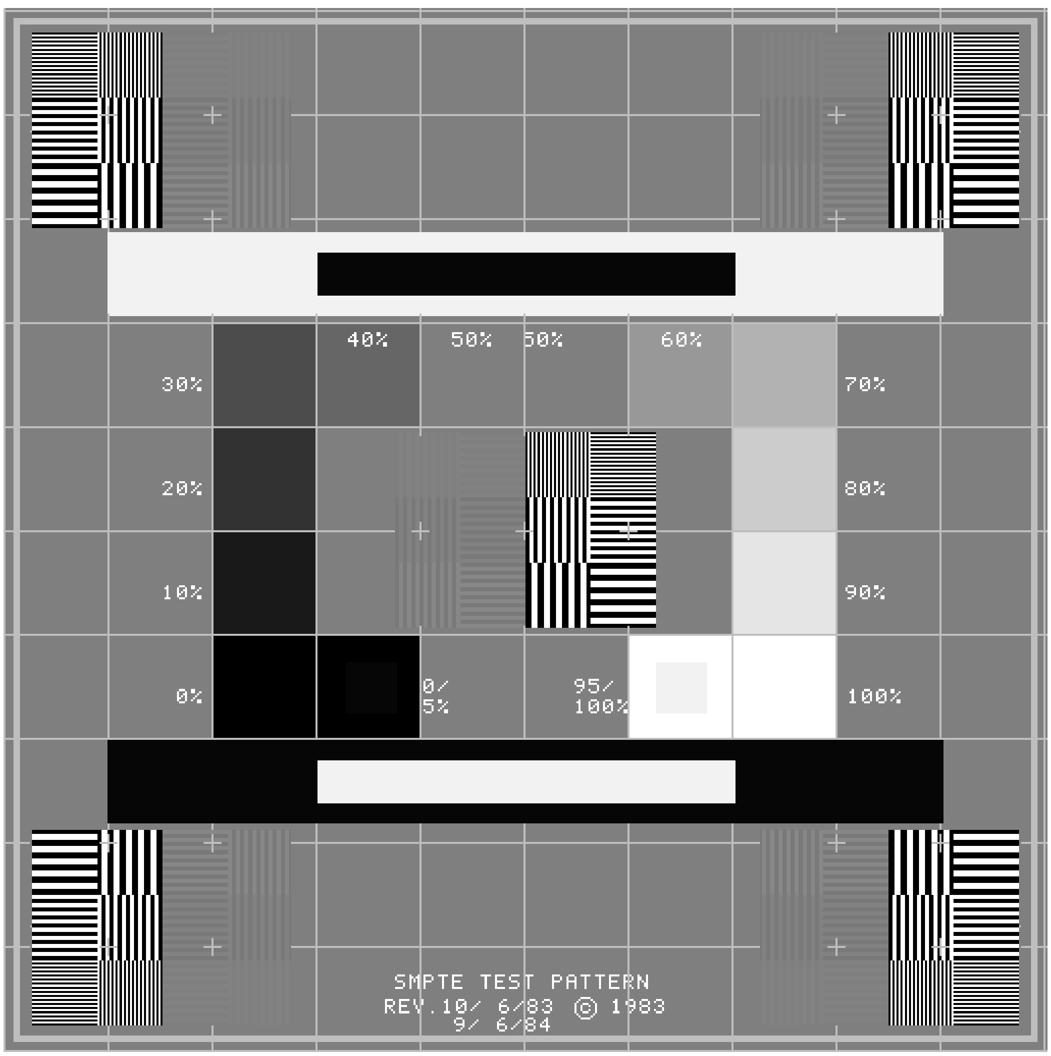


Figure II.8-1. SMPTE Test Pattern.

Data: Define pass by absence of noticeable ringing, undershoot, overshoot, or streaking.

The test pattern shown in Figure II.8-1 was used in the visual evaluation of the monitor. This test pattern is defined in SMPTE Recommended Practice RP-133-1986 published by the Society of Motion Picture and Television Engineers (SMPTE) for medical imaging applications. Referring to the large white-in-black and black-in-white horizontal bars contained in the test pattern, RP133-1986, paragraph 2.7 states " These areas of maximum contrast facilitate detection of mid-band streaking (poor low-frequency response), video amplifier ringing or overshoot, deflection interference, and halo." None of these artifacts was observed in the HITACHIMODEL monitor, signifying good electrical performance of the video circuits.

II.9. Addressability

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1, page 67.

This monitor properly displayed all addressed pixels for the following tested format (HxV): 1600 x 1200 x 72 Hz, 1024 x 1024 x 120 Hz.

Objective: Define the number of addressable pixels in the horizontal and vertical dimension; confirm that stated number of pixels is displayed.

Equipment: Programmable video signal generator.
Test pattern with pixels lit on first and last addressable rows and columns and on two diagonal lines beginning at upper left and lower right; H & V grill patterns 1-on/1-off.

Procedure: The number of addressed pixels were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible. All perimeter lines were confirmed to be visible, with no irregular jaggies on diagonals and, for monochrome monitors, no strongly visible moiré on grilles.

Data: If tests passed, number of pixels in horizontal and vertical dimension. If test fails, addressability unknown.

Table II.9-1 Addressabilities Tested

Monoscopic Mode	Stereo Mode
1600 x 1200	1024 x 1024

II.10. Pixel Aspect Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.10, p 8.

Pixel aspect ratio is 1:1.

Objective: Characterize aspect ratio of pixels.

Equipment: Test target, measuring tape with at least 1/16th inch increments

Procedure: Display box of 400 x 400 pixels at input count corresponding to 50% Lmax and background of 0. Measure horizontal and vertical dimension.

Alternatively, divide number of addressable pixels by the total image size to obtain nominal pixel spacings in horizontal and vertical directions.

Data: Define pass if H= V± 6% for pixel density <100 ppi and ± 10% for pixel density > 100 ppi.

	Monoscopic Mode
Addressability (H x V)	1600 x 1200
H x V Image Size (inches) H x V Pixel Spacing (mils) H x V Pixel Aspect Ratio	15.436 x 11.575 9.65 x 9.65 H = V + 0%

II.11. Screen Size (Viewable Active Image)

Reference: VESA Flat Panel Display Measurements Standard, Version 1.0, May 15, 1998, Section 501-1.

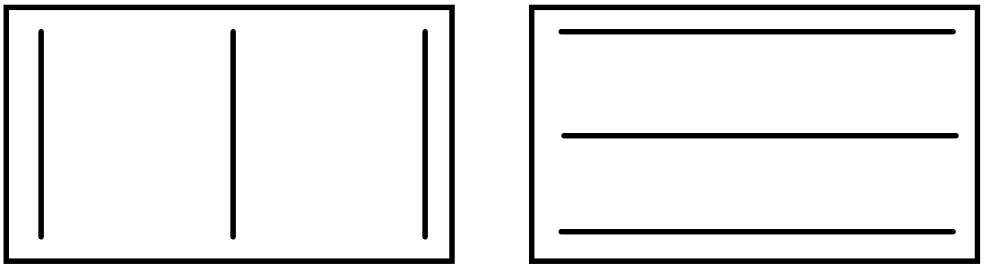
Image size as tested in monoscopic mode (1600 x 1200) was 19.294 inches in diagonal.

Objective: Measure beam position on the CRT display to quantify width and height of active image size visible by the user (excludes any overscanned portion of an image).

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.11-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be

positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.11-1 Three-line grille test patterns.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates of lines at the ends of the major and minor axes.

Data: Compute the image width defined as the average length of the horizontal lines along the top, bottom and major axis of the screen. Similarly, compute the image height defined as the average length of the vertical lines along the left side, right side, and minor axis of the screen. Compute the diagonal screen size as the square root of the sum of the squares of the width and height.

Table II.11-1. Image Size

	Monoscopic Mode
Addressability (H x V)	1600 x 1200
H x V Image Size (inches) Diagonal Image Size (inches)	15.436 x 11.575 19.294

II.12. Contrast Modulation

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 5.2, page 57.

Contrast modulation (Cm) for 1-on/1-off grille patterns displayed at 50% Lmax exceeded Cm = 35% in Zone A, and exceeded Cm = 30% in Zone B.

Objective: Quantify contrast modulation as a function of screen position.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Photometer with linearized response

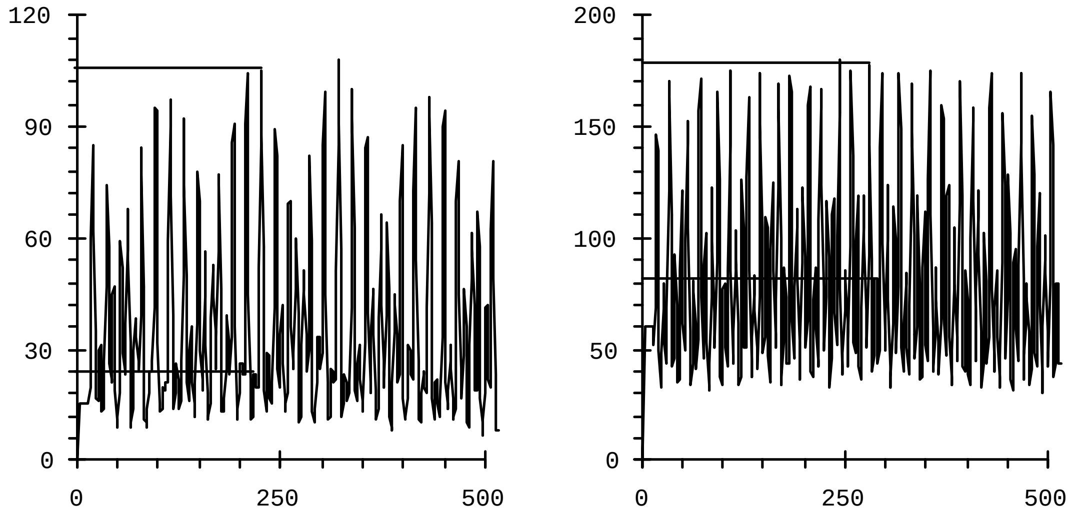
Procedure: The maximum video modulation frequency for each format (1600 x 1200) was examined using horizontal and vertical grille test patterns consisting of alternating lines with 1 pixel on, 1 pixel off. Contrast modulation was measured in both horizontal and vertical directions at screen center and at eight peripheral screen positions. The measurements should be along the horizontal and vertical axes and along the diagonal from these axes. Use edge measurements no more than 10% of screen size in from border of active screen. The input signal level was set so that 1-line-on/1-line-off horizontal grille patterns produced a screen area-luminance of 25% of maximum level, Lmax.

Zone A is defined as a 24 degree subtended circle from a viewing distance of 18 inches (7.6 inch circle). Zone B is the remainder of the display. Use edge measurements no more than 10% of screen size in from border of active screen area to define Cm for Zone B (remaining area outside center circle). Determine Cm at eight points on circumference of circle by interpolating between center and display edge measurements to define Cm for Zone A. If measurements exceed the threshold, do not make any more measurements. If one or more measurements fail the threshold, make eight additional measurements at the edge (but wholly within) the defined circle.

Data: Values of vertical and horizontal Cm for Zone A and Zone B are given in Table II.12-1. The contrast modulation, Cm, is reported (the defining equation is given below) for the 1-on/1-off grille patterns. The modulation is equal to or greater than 51% in Zone A, and is equal to or greater than 35% in Zone B.

$$C_m = \frac{L_{peak} - L_{valley}}{L_{peak} + L_{valley}}$$

The sample contrast modulations shown in Figure II.12-1 for two different color CRTs are not fully realized because of the presence of moiré caused by aliasing between the image and the shadow mask. Because contrast modulation values are calculated for the maximum peak and minimum valley luminance levels as indicated in the sample data shown, they do not include the degrading effects of aliasing.



Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Figure II.12-1. *Contrast modulation for sample luminance profiles (1 pixel at input level corresponding to 50% Lmax, 1 pixel at level 0 = Lmin) for monitors exhibiting moiré due to aliasing.*

Table II.12-1. Contrast Modulation
Corrected for lens flare and Zone Interpolation

Zone A = 7.6-inch diameter circle for 24-degree subtended angle at 18-inch viewing distance

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	75%	35%			32%	51%			68%	34%
			62%	41%	39%	49%	59%	41%		
Major	73%	34%	63%	40%	53%	46%	66%	38%	79%	30%
			60%	42%	64%	51%	58%	41%		
Bottom	71%	37%			70%	53%			66%	34%

Zone A = 9.54-inch diameter circle for 40% area

	Left				Minor				Right	
	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille	H-grille	V-grille
Top	75%	35%			32%	51%			68%	34%
			64%	40%	35%	50%	61%	40%		
Major	73%	34%	65%	38%	53%	46%	69%	36%	79%	30%
			62%	41%	67%	52%	60%	40%		
Bottom	71%	37%			70%	53%			66%	34%

II.13. Pixel Density

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.13, p 9.

Pixel density was 104 H x 104 V pixels per inch (ppi) as tested for the 1600 x 1200-line format.

Objective: Characterize density of image pixels

Equipment: Measuring tape with at least 1/16 inch increments

Procedure: Measure H&V dimension of active image window and divide by vertical and horizontal addressability

Data: Define horizontal and vertical pixel density in terms of pixels per inch

Table II.13-1. Pixel-Density

	Monoscopic Mode
H x V Addressability, Pixels	1600 x 1200
H x V Image Size, Inches H x V Pixel Density, ppi	15.436 x 11.575 104 x 104

II.14. Moiré

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.14, p 9.

Phosphor-to-pixel spacing ratios are less than 0.9 for the 1600 x 1200 format.

Objective: Determine lack of moiré.

Equipment Loupe with scale graduated in 0.001 inch or equivalent

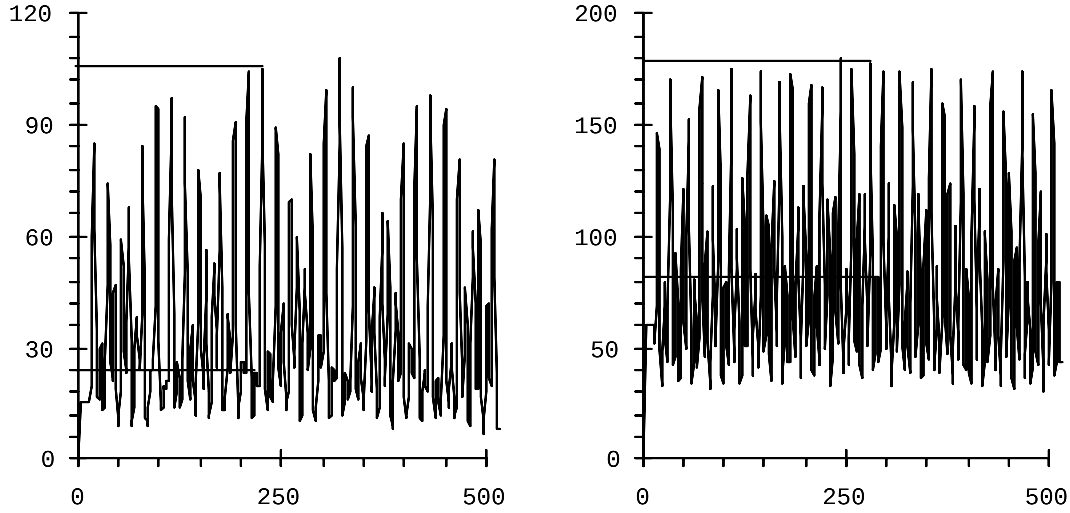
Procedure Measure phosphor pitch in vertical and horizontal dimension at screen center. For aperture grille screens, vertical pitch will be 0. Define pixel size by 1/pixel density.

Data: Define value of phosphor: pixel spacing. Value <1 passes, but <0.6 preferred.

Table II.14-1. Phosphor-to-Pixel-Spacing Ratios

	Monoscopic Mode
Addressability	1600 x 1200
Pixel Spacing (H x V	9.65 x 9.65 mils (0.245 mm x 0.245 mm)
Phosphor Pitch (H x V)	0.22 mm x 0.16 mm (measured)
Phosphor-to-Pixel-Spacing	0.90 H x 0.65 V

Discussion: Moiré occurs when the phosphor pitch is too large in comparison to the pixel size. Studies have shown that a phosphor pitch of about 0.6 pixels or less is required for adequate visibility of image information without interference from the phosphor structure.



Monitor A
0.28mm dot pitch

Monitor B
0.26mm dot pitch

Figure II.12-1. *Contrast modulation for sample luminance profiles (1pixel at level 50, 1 pixel at level 0) for monitors exhibiting moiré due to aliasing.*

In Figure II.12-1, Monitor A phosphor pitch is 0.90 pixels as compared with 0.84 pixels in Monitor B. Moiré is more visible in Monitor A, appearing as long stripes where contrast modulation has been degraded. In Monitor B, moiré is less visible, appearing as "fish-scales" where contrast modulation has been reduced. Even though the Monitor A exhibits a greater loss of contrast modulation from the presence of moiré on 1-on/1-off vertical grille patterns, there is little or no visual impact when aerial photographic images are displayed. NIDL experts in human vision and psychophysics were unable to discern presence of moiré on either monitor when grayscale imagery was displayed.

II.15. Straightness

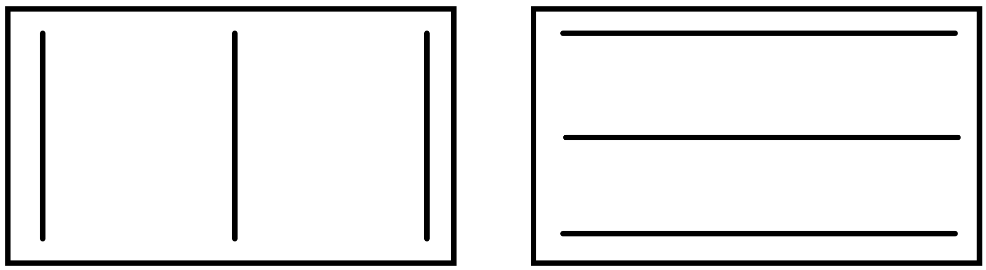
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.1 Waviness, page 67.

Waviness, a measure of straightness, did not exceed 0.20% of the total image height or width.

Objective: Measure beam position on the CRT display to quantify effects of waviness which causes nonlinearities within small areas of the display distorting nominally straight features in images, characters, and symbols.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.15-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern are displayed at 100% L_{max} must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



1-pixel-wide lines displayed at 100% L_{max}

Figure II.15-1 Three-line grille test patterns.

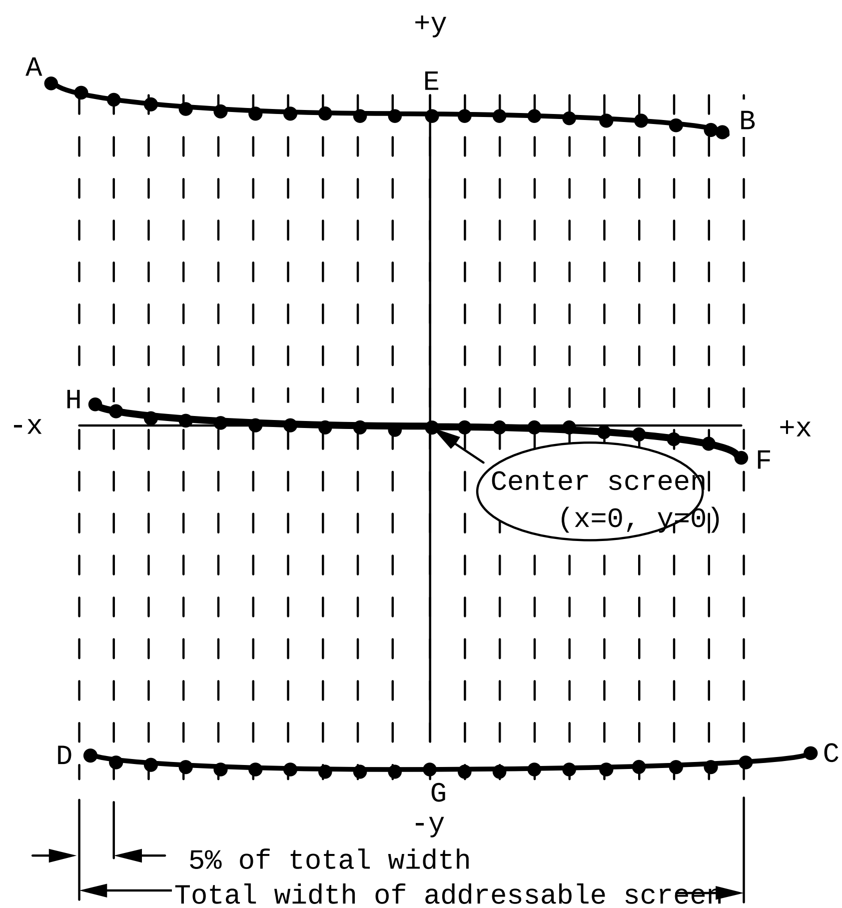


Figure II.15-2 Measurement locations for waviness along horizontal lines. Points A, B, C, D are extreme corner points of addressable screen. Points E, F, G, H are the endpoints of the axes.

Procedure: Use diode optic module to locate center of line profiles in conjunction with calibrated X-Y translation to measure screen x, y coordinates along the length of a nominally straight line. Measure x, y coordinates at 5% addressable screen intervals along the line. Position vertical lines in video to land at each of three (3) horizontal screen locations for determining waviness in the horizontal direction. Similarly, position horizontal lines in video to land at each of three (3) vertical screen locations for determining waviness in the vertical direction.

Data: Tabulate x, y positions at 5% addressable screen increments along nominally straight lines at top and bottom, major and minor axes, and left and right sides of the screen as shown in Table II.15-I. Figure II.15-3 shows the results in graphical form.

Table II.15-1. Straightness

Tabulated x, y positions at 5% addressable screen increments along nominally straight lines.

Top		Bottom		Major		Minor		Left Side		Right Side	
x	y	x	y	x	y	x	y	x	y	x	y
-7798	5707	-7796	-5918	-7792	-18	2	5680	-7798	5709	7633	5682
-7200	5707	-7200	-5916	-7200	-16	4	5400	-7800	5400	7635	5400
-6400	5707	-6400	-5910	-6400	-13	3	4800	-7800	4800	7634	4800
-5600	5703	-5600	-5902	-5600	-12	3	4200	-7800	4200	7633	4200
-4800	5700	-4800	-5897	-4800	-10	2	3600	-7800	3600	7633	3600
-4000	5696	-4000	-5889	-4000	-8	1	3000	-7799	3000	7632	3000
-3200	5691	-3200	-5882	-3200	-6	1	2400	-7798	2400	7634	2400
-2400	5689	-2400	-5875	-2400	-3	-1	1800	-7794	1800	7634	1800
-1600	5685	-1600	-5871	-1600	-2	-1	1200	-7794	1200	7635	1200
-800	5683	-800	-5866	-800	1	-1	600	-7793	600	7633	600
0	5679	0	-5864	0	1	0	0	-7793	0	7633	0
800	5677	800	-5862	800	2	1	-600	-7791	-600	7633	-600
1600	5677	1600	-5860	1600	2	2	-1200	-7793	-1200	7631	-1200
2400	5677	2400	-5861	2400	3	3	-1800	-7793	-1800	7631	-1800
3200	5679	3200	-5864	3200	3	3	-2400	-7795	-2400	7631	-2400
4000	5685	4000	-5864	4000	3	4	-3000	-7795	-3000	7631	-3000
4800	5687	4800	-5865	4800	2	4	-3600	-7793	-3600	7630	-3600
5600	5687	5600	-5869	5600	0	3	-4200	-7792	-4200	7629	-4200
6400	5687	6400	-5871	6400	-1	4	-4800	-7793	-4800	7631	-4800
7200	5683	7200	-5871	7200	-1	4	-5400	-7795	-5400	7636	-5400
7633	5682	7644	-5868	7644	-1	4	-5864	-7796	-5918	7644	-5872

1600 x 1200

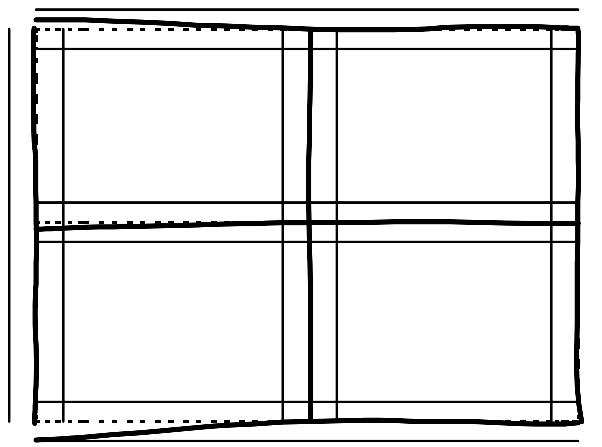


Figure II.15-3 Waviness of Hitachi CM814U Color monitor in 1600 x 1200 mode. Departures from straight lines are exaggerated on a 10X scale. Error bars are +/- 0.5% of total screen size.

II.16. Refresh Rate

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.16, p 9.

Vertical refresh rate for 1600 x 1200 format was set to 72 Hz. Vertical refresh rate for the 1024 x 1024 stereo format was set to 120 Hz (60 Hz per eye).

Objective: Define vertical and horizontal refresh rates.

Equipment: Programmable video signal generator.

Procedure: The refresh rates were programmed into the Quantum Data 8701 test pattern generator for 72 Hz minimum for monoscopic mode and 120 Hz minimum for stereoscopic mode, where possible.

Data: Report refresh rates in Hz.

Table II.16-1 Refresh Rates as Tested

	Monoscopic Mode	Stereo Mode
Addressability	1600 x 1200	1024 x 1024
Vertical Scan Horizontal Scan	72 Hz 90 kHz	116 Hz 125 kHz

II.17. Extinction Ratio

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.17, p10.

Stereo extinction ratio was averaged to 11.25:1 (11.2 left, 11.3 right) at screen center. Luminance of white varied by up to 11.7% across the screen. Chromaticity variations of white were less than 0.006 delta u'v' units.

Objective: Measure stereo extinction ratio

Equipment: Two “stereo” pairs with full addressability. One pair has left center at command level of 255 (or Cmax) and right center at 0. The other pair has right center at command level of 255 (or Cmax) and left center at 0.

Stereoscopic-mode measurements were made using a commercially-available Nuvision 19-inch LCD shutter with passive polarized eyeglasses.

Procedure: Calibrate monitor to 0.1 fL Lmin and 35 fL Lmax (no ambient). Measure ratio of Lmax to Lmin on both left and right side images through the stereo system.

Data: Extinction ratio (left) = L (left,on, white/black)/left,off, black/white)

L(left,on, white/black) ~ trans(left,on)*trans(stereo)*L(max)*Duty(left)
+ trans(left,off)*trans (stereo)*L(min)*Duty (right)
Use left,off/right,on to perform this measurement

Extinction ratio (right) = L (right,on,white/black)/right,off, black/white)

L(right,on, white/black) ~
trans(right,on)*trans(stereo)*L(max)*Duty(right)
+ trans(right,off)*trans (stereo)*L(min)*Duty (left)
Use left,on/right,off to perform this measurement

Stereo extinction ratio is average of left and right ratios defined above.

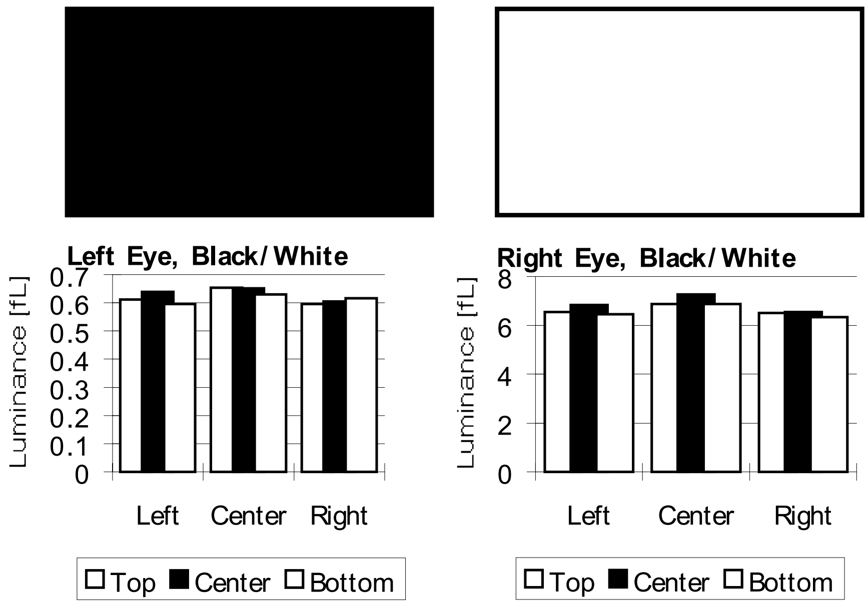


Fig.II.17-1. Spatial Uniformity of luminance in stereo mode when displaying black to the left eye while displaying white to the right eye.

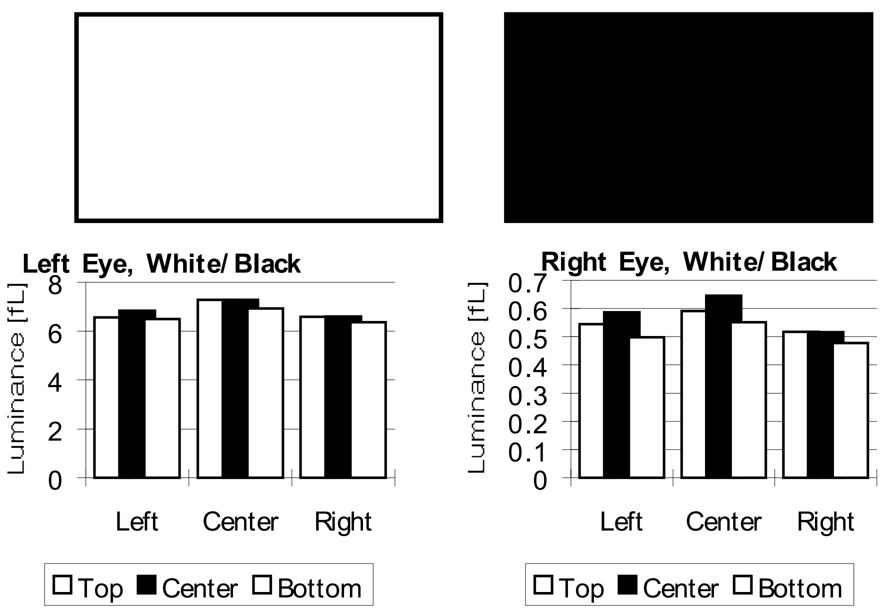


Fig.II.17-2. Spatial Uniformity of luminance in stereo mode when displaying white to the left eye while displaying black to the right eye.

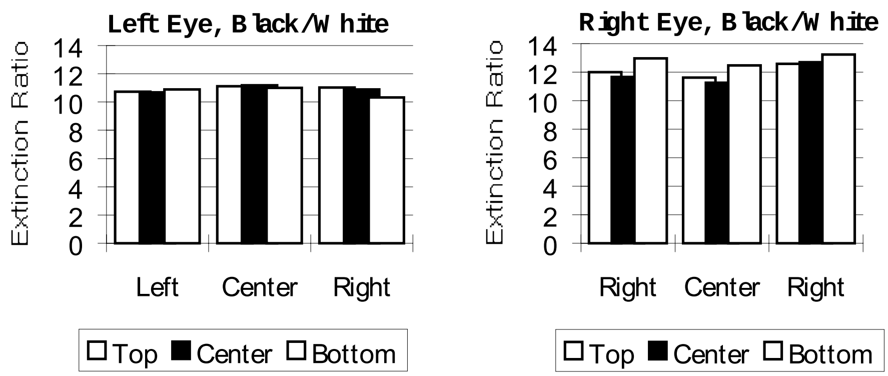


Fig.II.17-3. Spatial Uniformity of extinction ratio in stereo mode.

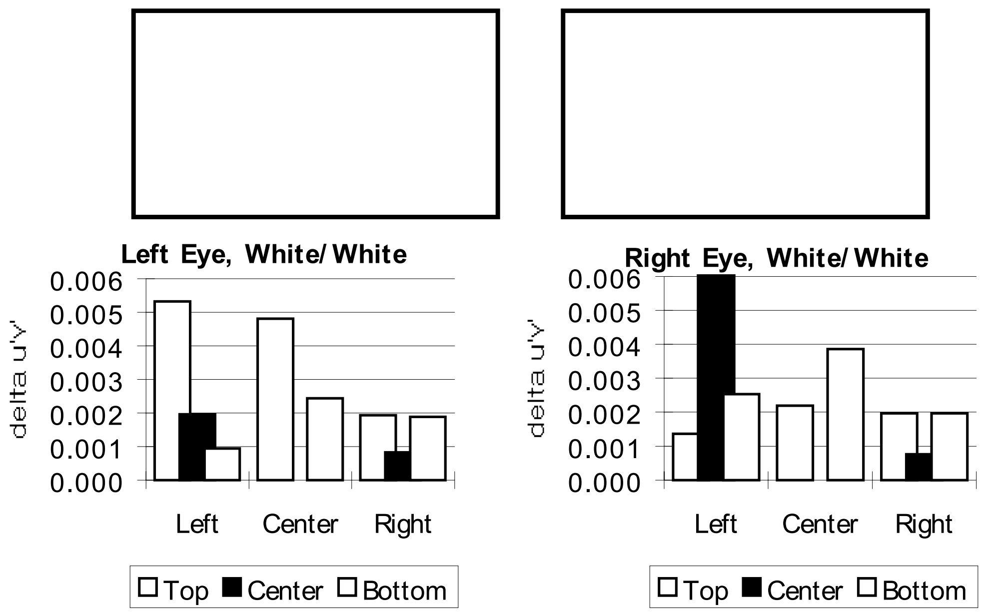


Fig.II.17-4 Spatial uniformity of chromaticity of white in stereo mode.

II.18. Linearity

Reference: Monochrome CRT Monitor Performance, Draft Version 2.0, Section 6.2, page 73.

The maximum nonlinearity of the scan was 1.78 % of full screen. NIDL could not adjust the linearity from the monitor's front panel.

Objective: Measure the relation between the actual position of a pixel on the screen and the commanded position to quantify effects of raster nonlinearity. Nonlinearity of scan degrades the preservation of scale in images across the display.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use grille patterns of single-pixel horizontal lines and single-pixel vertical lines displayed at 100% L_{max}. Lines are equally spaced in addressable pixels. Spacing must be constant and equal to approximately 5% screen width and height to the nearest addressable pixel as shown in Figure II.18-1.

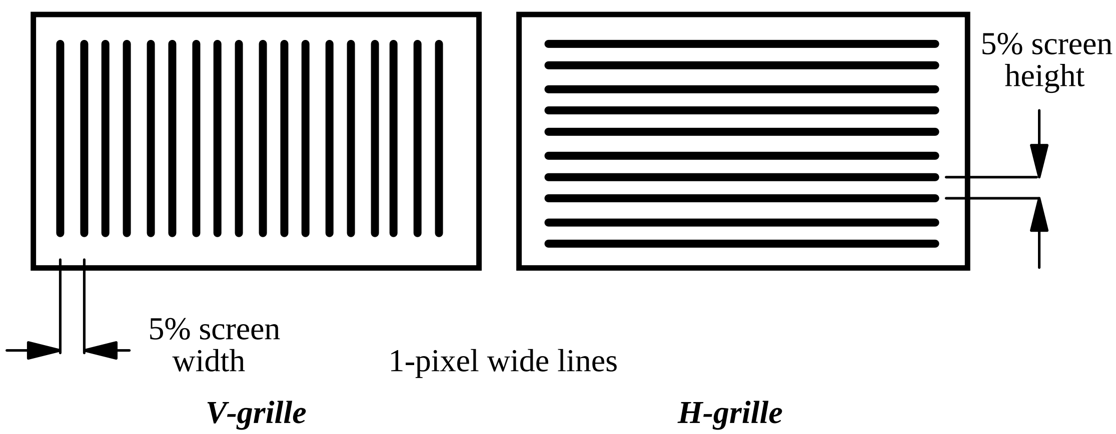


Figure II.18-1. *Grille patterns for measuring linearity*

Procedure: The linearity of the raster scan is determined by measuring the positions of lines on the screen. Vertical lines are measured for the horizontal scan, and horizontal lines for the vertical scan. Lines are commanded to 100% Lmax and are equally spaced in the time domain by pixel indexing on the video test pattern. Use optic module to locate center of line profiles in conjunction with x, y-translation stage to measure screen x, y coordinates of points where video pattern vertical lines intersect horizontal centerline of screen and where horizontal lines intersect vertical centerline of the CRT screen as shown in Figure II.18-2.

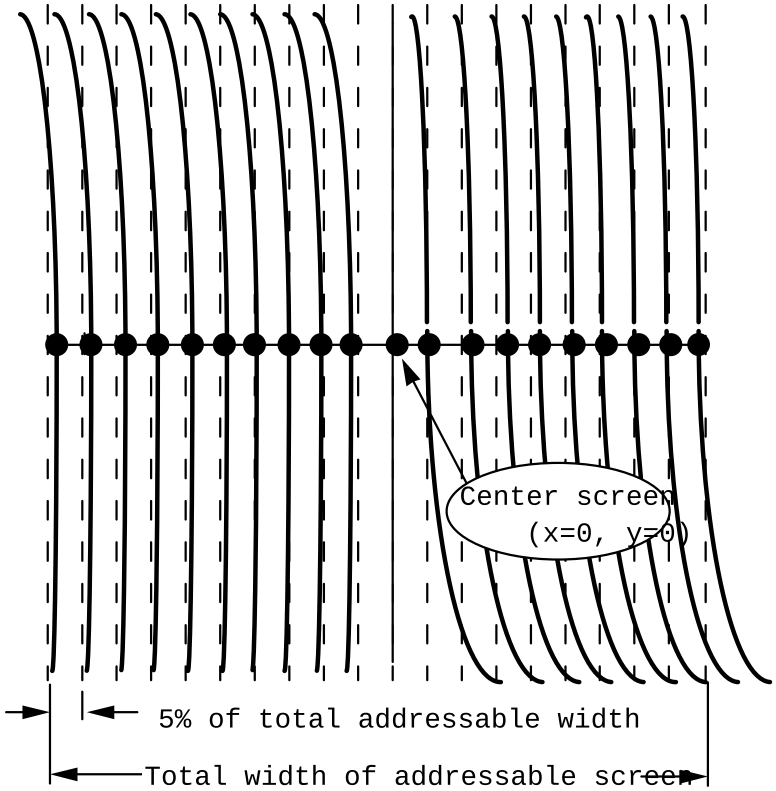


Figure II.18-2. *Measurement locations for horizontal linearity along the major axis of the display. Equal pixel spacings between vertical lines in the grille pattern are indicated by the dotted lines. The number of pixels per space is nominally equivalent to 5% of the addressable screen size.*

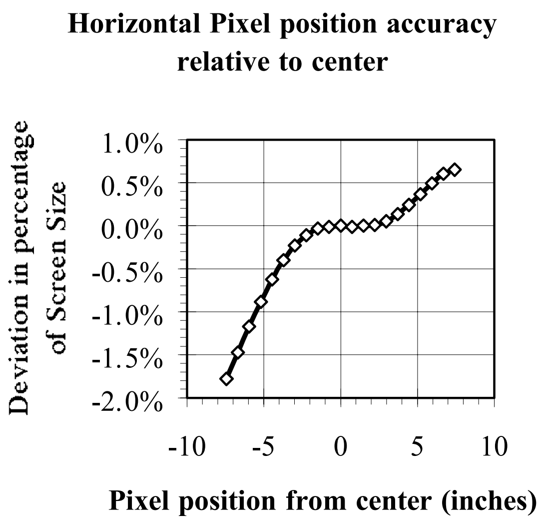
Data: Tabulate x, y positions of equally spaced lines (nominally 5% addressable screen apart) along major (horizontal centerline) and minor (vertical centerline) axes of the raster. If both scans were truly linear, the differences in the positions of adjacent lines would be a constant. The departures of these differences from constancy impacts the absolute position of each pixel on the screen and is, then, the nonlinearity. The degree of nonlinearity may be different between left and right and between top and bottom. The maximum horizontal and vertical nonlinearities (referred to full screen size) are listed in table II.18-1. The complete measured data are listed in table II.18-2 and shown graphically in Figure II.18-3.

Table II.18-1. Maximum Horizontal and Vertical Nonlinearities between equal spacings

Format	Left Side	Right Side	Top	Bottom
1600 x 1200	1.78%	0.65%	0.07%	1.14%

Table II.18-2. Horizontal and Vertical Nonlinearities Data

Vertical Lines x-Position (mils)		Horizontal lines y-Position (mils)	
Left Side	Right Side	Top	Bottom
-7701	7529	5616	-5739
-6911	6779	5057	-5150
-6122	6019	4493	-4562
-5336	5257	3931	-3979
-4553	4495	3367	-3402
-3776	3736	2807	-2829
-3007	2980	2247	-2256
-2246	2230	1686	-1688
-1491	1486	1124	-1120
-745	741	563	-559
0	0	0	0



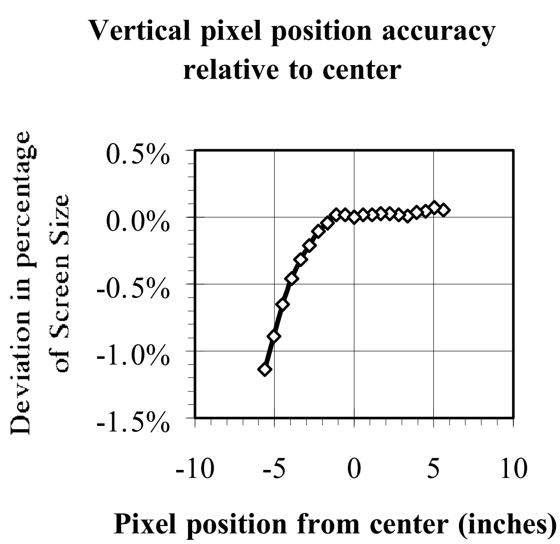


Fig. II.18-5 Horizontal and vertical linearity characteristics.

II.19. Jitter/Swim/Drift

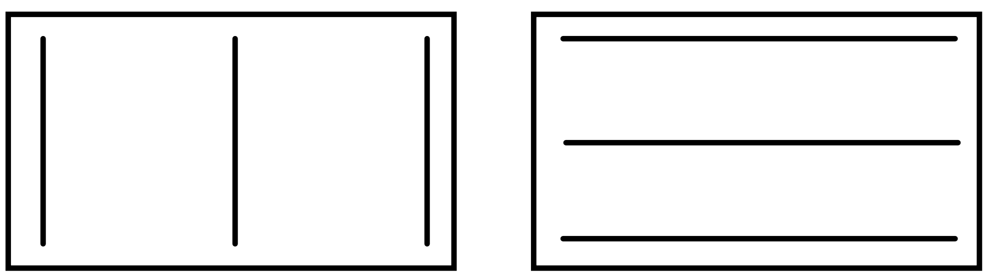
Reference: Monochrome CRT Monitor Performance, Draft Version 2.0 Section 6.4, p80.

Maximum jitter and swim/drift were 2.44 mils and 2.68 mils, respectively.

Objective: Measure amplitude and frequency of variations in beam spot position of the CRT display. Quantify the effects of perceptible time varying raster distortions: jitter, swim, and drift. The perceptibility of changes in the position of an image depend upon the amplitude and frequency of the motions which can be caused by imprecise control electronics or external magnetic fields.

Equipment:
- Video generator
- Spatially calibrated CCD or photodiode array optic module
- Calibrated X-Y translation stage

Test Pattern: Use the three-line grille patterns in Figure II.19-1 for vertical and horizontal lines each 1-pixel wide. Lines in test pattern must be positioned along the top, bottom, and side edges of the addressable screen, as well as along both the vertical and horizontal centerlines (major and minor axes).



V-grille for measuring horizontal motion H-grille for measuring vertical motion

1-pixel wide lines

Three-line grille test patterns.
Figure II.19-1

Procedure: With the monitor set up for intended scanning rates, measure vertical and horizontal line jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration as displayed using grille video test patterns. Generate a histogram of raster variance with time. The measurement interval must be equal to a single field period.

Optionally, for multi-sync monitors measure jitter over the specified range of scanning rates. Some monitors running vertical scan rates other than AC line frequency may exhibit increased jitter.

Measure and report instrumentation motion by viewing Ronchi ruling or illuminated razor edge mounted to the top of the display. It may be necessary to mount both the optics and the monitor on a vibration damped surface to reduce vibrations.

Data: Tabulate motion as a function of time in x-direction at top-left corner screen location. Repeat for variance in y-direction. Tabulate maximum motions (in mils) with display input count level corresponding to L_{max} for jitter (0.01 to 2 seconds), swim (2 to 60 seconds) and drift (over 60 seconds) over a 2.5 minute duration. The data are presented in Table II.19-1. Both the monitor and the Microvision equipment sit on a vibration-damped aluminum-slab measurement bench. The motion of the test bench was a factor of 10 times smaller than the CRT raster motion.

Table II.19-1. Jitter/Swim/Drift
Time scales: Jitter 2 sec., Swim 10 sec., and Drift 60 sec.

1600 x 1200 x 72 Hz

Signal Generator		**Quantum Data FOX 8701**	
Position		H-lines	V-lines
10D corner	Max Motions		
	Jitter	2.44	2.27
	Swim	2.68	2.46
	Drift	2.68	2.46

II.20 Warm-up Period

Reference: Request for Evaluation Monitors, NIDL Pub. 0201099-091, Section 5.20, p. 10.

A 60-minute warm-up was necessary for luminance stability of Lmin = 0.1 fL +/- 10%.

Objective: Define warm-up period

Equipment: Photometer, test target (full screen 0 count)

Procedure: Turn monitor off for three-hour period. Turn monitor on and measure center of screen luminance (Lmin as defined in Dynamic range measurement) at 1-minute intervals for first five minutes and five minute intervals thereafter. Discontinue when three successive measurements are ± 10% of Lmin.

Data: Pass if Lmin within ± 50% in 30 minutes and ±10% in 60 minutes.

The luminance of the screen (commanded to the minimum input level, 0 for Lmin) was monitored for 120 minutes after a cold start. Measurements

were taken every minute. Figure II.20-1 shows the data for 1600 x 1200 format in graphical form. The luminance remains very stable after 49 minutes.

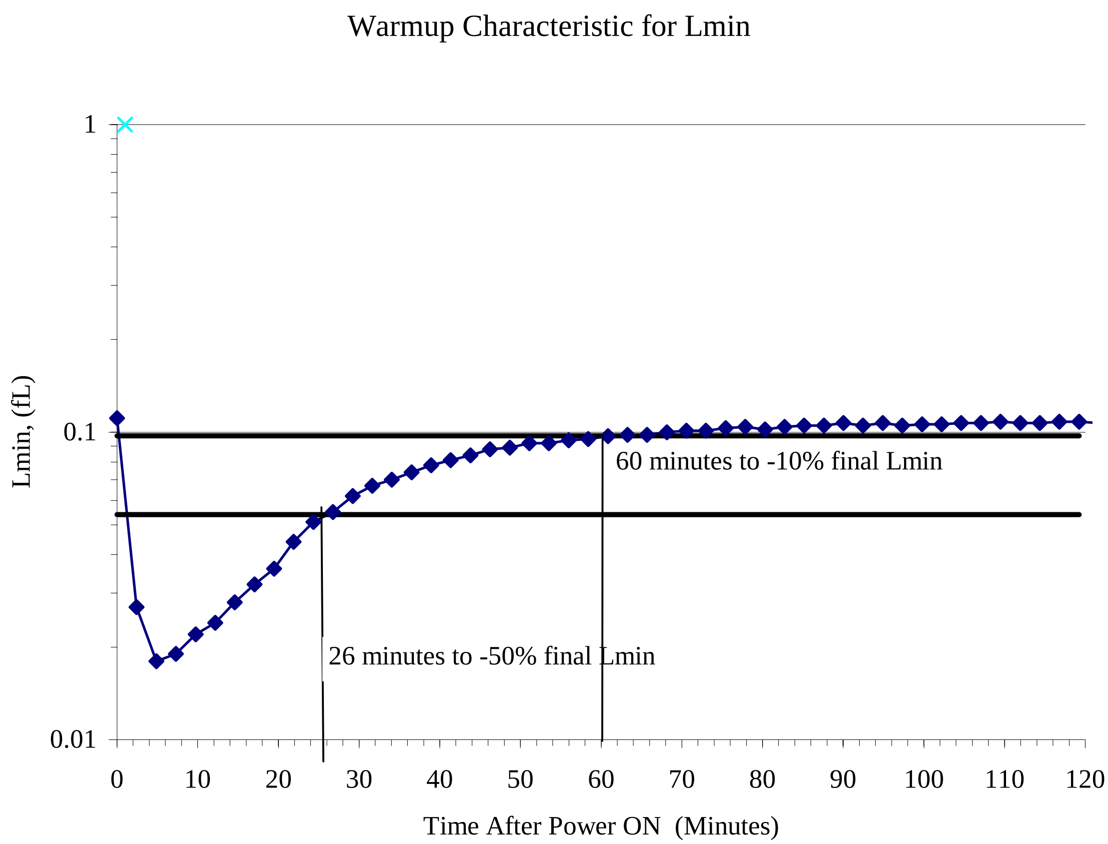


Figure II.20.1. Luminance (fL) as a function of time (in minutes) from a cold start with an input count of 0. (Note suppressed zero on luminance scale).